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Life Cycle Cost Modeling of Conceptual Space Vehicles

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LIFE CYCLE COSTING
FOR CONCEPTUAL SPACE SYSTEMS
Semiannual Status Report

1.0 Introduction

The University of Dayton is pleased to submit this status report to the National Aeronautics and Space Administration (NASA) Langley Research Center which documents progress to date on the development of a life cycle cost model for use during the conceptual design of new launch vehicles and spacecraft. This research is being conducted under NASA Research Grant NAG-1-1327. This research effort changes the focus from that of the first two years in which a reliability and maintainability model was developed to the initial development of a life cycle cost model. Cost categories are initially patterned after NASA's three axis work breakdown structure consisting of a configuration axis (vehicle), a function axis, and a cost axis. The focus will be on operations and maintenance costs and other recurring costs. Secondary tasks performed concurrent with the development of the life cycle costing model include continual support and upgrade of the R&M model. The primary result of the completed research will be a methodology and a computer implementation of the methodology to provide for timely cost analysis in support of the conceptual design activities.

1.1 Research Objectives

The major objectives of this research are:

a. to obtain and to develop improved methods for estimating manpower, spares, software and hardware costs, facilities costs, and other cost categories as identified by NASA personnel;

b. to construct a life cycle cost model of a space transportation system for budget exercises and performance- cost trade-off analysis during the conceptual and development stages,

c. to continue to support modifications and enhancements to the R&M model;

d. to continue to assist in the development of a simulation model to provide an integrated view of the operations and support of the proposed system.

1.2 Current Status

The following tasks, as defined in the proposal, have been completed:

Task 1. (Problem Definition) Cost categories for inclusion in the life cycle cost model have been identified. These costs are based upon the three axis work breakdown structure and will include recurring hardware, software, facilities, and manpower costs. Hardware includes vehicle spares and expendables as well as ground support equipment. A proposed Cost Element Structure (CES) based upon the intersection of the vehicle WBS (configuration), function (operations, logistics, sustaining engineering, and program management), and costs, as well as a comparative analysis of other LCC models, has been identified in Section 2.0. This CES is recommended to NASA for consideration as a formalized cost accounting process.

Task 2. (Literature Search) An extensive literature review to determine existing methodologies for estimating costs in each of the major categories identified in Task 1 has been completed. Some of the cost estimating relationships identified during this task will be utilized in the initial version of the life cycle cost model. Defense Department and contractor life cycle costing models provide cost data and parametric cost relationships relevant to this study. Section 3.0 summarizes these references and compares and contrasts various LCC models. A completed bibliography is also provided.

Task 3. (Data Collection) From Task 1 and Task 2, cost categories not addressed or not appropriate for use in the space environment were identified. Shuttle and contractor cost data to support the development of new cost estimating relationships particular to space shuttle and other space operations have been obtained. In particular, data to support the life cycle costing of facilities has been obtained from the Air Force. This data and the resulting methodology is described in Section 5.0.

The following tasks have been initiated and are in various stages of completion:

Task 4. (Data Analysis) Parametric cost estimating equations based upon the facilities data obtained in Task 3 have been developed. These equations are documented in Section 5.0. Section 4.0 describes the general methodology to be utilized in the LCC model. This methodology is a result of the insight obtained from the three previous tasks.

Task 5. (Model Development) Based upon the Cost Element Structure and the available and derived parametric cost equations, work has begun on the initial costing model. The model has been structured to include RDT&E costs, investment or acquisition costs, and operations and support (logistics) costs. This model includes inflation factors and will discount costs to a base year. This LCC model utilizes output from the R&M model. Costs will also be computed in present day dollars or discounted to future years. This initial model development will be presented to NASA in order to obtain feedback for the development of a follow-on version.

Task 6. (Model Implementation) An initial PC model has been completed for NASA's review. This program is written in compiled BASIC and is compatible with the previously developed R&M model.

Task 7. (R&M Upgrade) Several changes have been accomplished to the R&M model. These include (1) using a weighted average to compute the vehicle manhour per maintenance action factor, (2) redefining ground processing and ground power-on times, (3) converting pad and integration time from hours to days, (4) changing the input parameter from flights per month to flights per year, (5) computing an air abort rate (not integrated into model), (6) computing the number of maintenance crews to be assigned, and (7) providing a hard copy reports generator module.

2.0 Cost Element Structure

We have reviewed DTIC, NASA, and commercial sources of cost element structure information. We have also conducted personal interviews with professionals working in the life cycle cost (LCC) and in the cost element structure area which make up the LCC structure. This section represents a distillation of the information presented by the people working in this area and the references appropriate for use in the NASA environment for LCC modeling.

2.1 Background

A cost element structure (CES) is a methodical representation of the economic activities which make-up an economic entity. The purpose of the structure is to provide visibility to the costs of interest. The cost element structure provides a hierarchial ordering of the costs where the greatest detail is rolled-up into ever higher and larger aggregation of costs. The degree of cost roll-up necessary is dependant upon the initial cost detail and structure. A cost element structure can be used to track the ongoing operations of an economic entity or to predict the future financial condition of an economic entity.

2.2 Program Categories

To track the economic activity of a program the most commonly used cost element structure, in government projects, matches the CES used in how the money is received from the funding organization or congress. This matching of cost categories extends to the level of detail required by the management structure of the organization working the project and the funding organization's requirements. The costs at the lowest level (greatest detail) of the cost element structure is determined by one of two methods, actual cost figures (if they are available) or estimates of the cost figures (typically used in estimating a conceptual program or early in the life cycle of the program). The method used is determined by the availability and quality of actual cost data to be used in the predictive model. A schematic representation of the program phase and estimation technique is shown below.

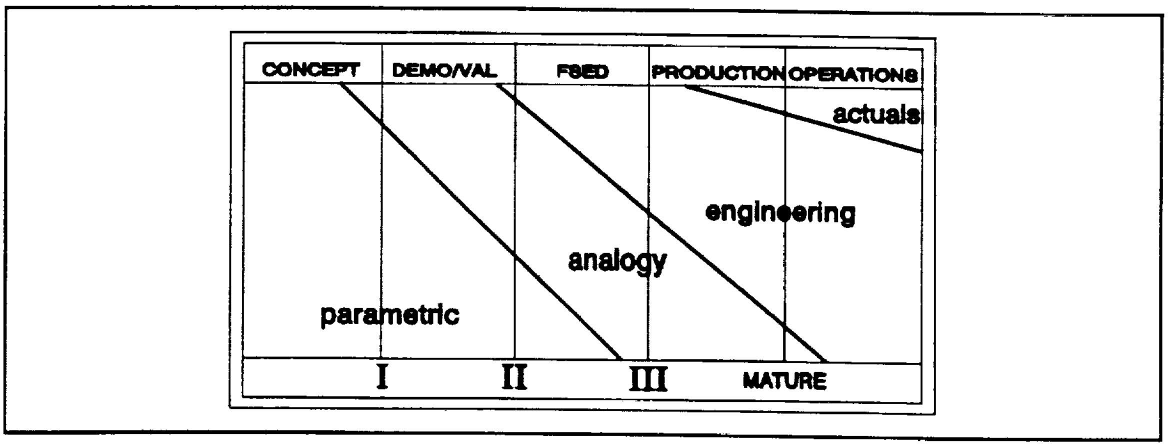

Figure 1 Cost Estimation Technique

A production program goes though a well defined sequence of stages. Briefly, the stages are :

Concept Development - Initial definition of the program elements and the structure of the systems composing the program at a gross level. Technologies are identified and the general subsystem operational parameters and requirements are identified.

Demonstration/Validation (DEM/VAL) - Refinement of the system parameters with the production of test article(s) for further verification of the ability to meet the requirements with the current design. System parameters are relatively well defined and the costs of the systems are becoming more complete.

Full Scale Early Deployment (FSED) - Initial production runs of the system where system parameters are well defined and the costs well understood.

Production - Full production of the system. The system costs are known and the systems parameters are fixed. Operational costs can be estimated accurately at this point.

Operations - The system has entered service and all the costs associated with the system are known and the operational cost are being developed.

An alternative method to define the system stages and the comparison to the system method shown are Research and Development (concept development and dem/val), Production (FSED and production), Operating and Support (operations), and Disposal. The alternative system stage definitions are given in the discussion below.

> <u>Research and Development</u> are those costs associated with research, development, test, and evaluation of system hardware and software. More specifically, it includes the cost of feasibility studies; simulation or modeling; engineering design, development, fabrication, assembly, and test of prototype hardware; initial system evaluation; associated documentation; and test of software.
>
> <u>Production</u> are those costs associated with producing the system, initial support equipment, training, technical and management data, initial spares and repair parts, plus any other items required to introduce a new system.
>
> <u>Operating and Support</u> is the cost of personnel, material, and facilities of both a direct and indirect nature required to operate, maintain, and support the hardware and software of the system.
>
> <u>Disposal</u> is the cost associated with disposing of a system at the end of its useful life, minus any salvage value. This category is seldom estimated in most analyses. Often this value is very small in comparison to the other three cost categories. The space vehicle and associated systems may be placed in storage at the end of their economic life, similar to the airline industry storing aircraft in

the desert. However, disposal can be an important consideration when evaluating alternative designs in which some designs use toxic materials and other designs do not.[1]

The descriptions of the two different representations of the life cycle of a project parallel each other very closely. The primary difference is emphasis placed in the first representation on the early phases of a program while the second includes the cost of disposal of the system. In order to follow the guidance of DoD's cost analysis improvement group (CAIG) we will follow a variant of the second representation of the life cycle of a project.

The DoD, to increase the consistency of the their cost estimating products and methods, has mandated that all cost information adhere to standards developed by the CAIG. The CAIG has developed their standards in response to the Congress' requests for consistent and verifiable cost data and estimates. This structure can be extended to the level of detail necessary to support the program under study. The general cost structure for O&S costs (taken from the CORE[2] model) used by DoD is shown on the next page.

The **Primer on Operating & Support (O&S) Costs of Space Systems**[3] is a brief (15 pages) discussion of the philosophy of the distribution of costs (primarily O&S) for spaced based systems. It outlines the allocation of direct and indirect costs in a formal manner for space based systems. The costs include both the ground and space/airborne assets used in the particular mission. The driving emphasis is on uniformity in compliance with the directives from the CAIG. The directives allow a wide latitude for program or system unique costs to be incorporated into the CAIG approved cost structure (typically the modular life cycle cost model (MLCCM)).

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[1] "Operating and Support Cost Estimating, A Primer," Major Thomas E. May, 1982

[2] AFI 655-03

[3] "Primer on Operating and Support (O&S) Costs of Space Systems," Robert Lamontagne, 1985

Cost-Oriented Resource Estimating (CORE) Model.
O&S Cost Categories

1.0 Unit Mission Personnel

1.1 Operations
1.1.1 Aircrew

1.2 Maintenance
1.2.1 Organizational Maintenance
1.2.1.1 Military Pay
1.2.1.2 Civilian Pay
1.2.2 Intermediate Maintenance
1.2.2.1 Military Pay
1.2.2.2 Civilian Pay
1.2.3 Ordnance Maint.
1.2.3.1 Military Pay
1.2.4 Other Maint. Personnel
1.2.4.1 Military Pay
1.2.4.2 Civilian Pay

1.3 Other Mission Personnel
1.3.1 Unit Staff
1.3.1.1 Military Pay
1.3.1.2 Civilian Pay
1.3.2 Security
1.3.2.1 Military Pay
1.3.3 Other
1.3.3.1 Military Pay
1.3.3.2 Civilian Pay

2.0 Unit Level Consumption

2.1 POL/Energy Consumption
2.1.1 POL
2.1.2 Field Generated Electricity
2.1.3 Commercial Electricity

2.2 Consumable Material/Repair Parts
2.2.1 Maintenance Material
2.2.1.1 Acft Maint Material
2.2.2 Operational Material
2.2.3 Mission Support Supplies

2.3 Depot Level Reparables

2.4 Training Munitions/Expendable Stores
2.5 Other

3.0 Intermediate Maintenance (External to unit)

3.1 Maintenance
3.1.1 Military Pay
3.1.2 Civilian Pay
3.2 Consumable Materiel/Repair Parts
3.3 Other

4.0 Depot Maintenance

4.1 Overhaul/Rework
4.1.1 Airframe
4.1.2 Engine Rework
4.1.3 Component Repair
4.1.4 Support Equipment
4.1.5 Modifications

4.2 Other Depot
4.2.1 General Depot Support
4.2.2 Second Destination Transportation
4.2.3 Contracted Unit Level Support

5.0 Contractor Support
5.1 Interim Contractor Support
5.2 Contractor Logistics Support
5.3 Other

6.0 Sustaining Support

6.1 Support Equipment Replacement
6.2 Modification Kit Procurement/Installation
6.3 Other Recurring Investment
6.4 Sustaining Engineering Support

6.5 Software Maintenance Support

6.6 Simulator Operations

6.7 Other

7.0 Indirect Support

7.1 Personnel Support

7.1.1 Medical Support

7.1.1.1 Military Pay
7.1.1.2 Civilian Pay

7.1.1.3 Non-pay/Material

7.1.2 Specialty Training
7.1.2.1 Pilot Training
7.1.2.2 Non-Pilot Aircrew Tng
7.1.2.2.1 Officer
7.1.2.2.2 Enlisted
7.1.2.3 Non-Aircrew Tng

7.1.2.3.1 Officer
7.1.2.3.2 Enlisted
7.1.2.3.3 Civilian

7.1.3. PCS

7.1.3.1 Officer
7.1.3.2 Enlisted
7.1.3.3 Civilian

7.2 Installation Support

7.2.1 Base Operating Support Personnel

7.2.1.1 Military
7.2.1.2 Civilian

7.2.2. Real Property Maint. Personnel

7.2.2.1 Military
7.2.2.2 Civilian

7.2.3 Installation Support Non-Pay

2.3 Cost Categories

In general there are two different types of costs. The first is fixed, which doesn't depend on the number of units of a particular item produced, like the rent of a warehouse. The other is variable, which depends upon the number of units produced, as in the total cost of raw materials. A third category of cost is also recognized, one that includes both fixed and variable components. An example of this kind of cost is the royalty paid for the use of a patented production method which has a yearly premium and an additional payment required for each piece produced. The costs can be further apportioned into direct and indirect costs.

Direct costs are those costs which result directly with the action of working the project. Typical direct costs are the labor costs of the people working the project and the cost of the materials. Indirect costs are the costs of a program which cannot be uniquely attributed to an action of working the contract, but the cost is required to support the project. Typical indirect costs are benefits for the employees, the apportioned cost of operation of the physical plant and facilities, senior management not working directly on projects but required for the operation of the project team, and staff functions not directly working the project like personnel.

In developing a life cycle model direct costs are computed from the estimated staffing and material required at each phase of a project. The indirect costs have been computed historically as a percentage of the direct charges. This procedure is well understood and has been accepted as a valid method for computing the indirect charges of a program, particularly when contractors are involved with a program since their indirect charge rate is usually preapproved. We will follow the method of computing indirect charges as a percentage of the direct charges.

2.4 Traditional Models

Traditional CES have relied upon a planar representation of the cost data with the project activities and subsystems (data, power storage, etc.) along one axis and the cost elements (labor, material, etc.) along the other. Each stage of the life cycle is represented by a different "sheet." This description of the cost element structure was driven by the difficulty of visualizing a three dimensional spreadsheet and the fact a 3-D spreadsheet didn't exist when most of the LCC models were developed due to the limitations of most of the mainframe computers used to develop the CES's.

Several LCC models used within DoD (primarily the Air Force) and industry include the Reliability, Maintainability and Cost Model (RMCM), Frieman Analysis of Systems Technique (FAST-E), Programmed Review of Information for Costing and Evaluation (PRICE) model, the (TI-59 ATL^2C^2) TI-59 Handheld Calculator Aircraft Top Level Life Cycle Cost (ATL^2C^2), the Avionics Laboratory Predictive Operations and Support (ALPOS) Cost Model, and variants on the Modular Life Cycle Cost Model (MLCCM) illustrate the differences and similarities in representing the CES of a program. These models are summarized at the end of this report. The MLCCM represents the standard LCC model of the US Air Force. Most other cost models are derived from this model.

2.5 Three-Axis Model

The three-axis LCC model presents CES information in a compact format. The consolidated format allows rapid investigation of different relationships depending upon which face of the "cube" is investigated and at what level. The implementation of the "cube" requires more thought and planning than a more traditional "flat" presentation. The additional planning is a result of resolving the interrelationships (where the three axis cross) and to ensure proper the cell contains the appropriate formula. The information required to fill a cubic presentation with appropriate formulas at each intersection of the cell faces is not available. This results in many empty cells. The result is that in some cases the effort required to develop a cubic presentation is not justified in terms of the additional information to be gained by studying the interrelationships between the different cube faces and what cell intersections are used. The degree to which each cell in the cube is filled is dependent upon the degree of refinement in the data used in creating the formulas in each cell. The cubic format lends itself to the representation of the interrelationships of data if information to fill the cells is abundant and of a high quality, so interpretation of the results of each cell has the same relevance and relationship to every other cell. The user doesn't have to discount the validity of a particular cell and explain this lack of confidence to people who are not familiar with the model and its methodologies and limitations.

2.6 Evaluation of Cost Element Structures

In comparing a particular life cycle cost model's CES to other models the overriding criterion is the utility to the user. This utility encompasses both the utility of the computer and its program and the physical presentation of the material matching the requirements of the user. The physical presentation matching the user's requirements is the major basis of comparison of any model. The model's operation should be transparent to the user. To use the model should not require any computer sophistication. Modification to the model should be as easy as possible. The models themselves should encompass some basic categories. The degree of detail below this level is driven by the user's requirements. The structure of the LCC should match the current tracking system for costs or else additional expenses will be incurred to gather the additional cost data to create the additional categories. Gathering additional cost data could imposes an undue strain on the existing cost tracking system, so great care must be exercised in requiring the reporting additional costing data. In most large government organizations the cost tracking is performed by contractors performing the work and the imposition of additional requirements for cost data usually results in additional expenses added to the existing contract and possible delay in the delivery of currently required costing data. The data requirements should be determined prior to the release of a contract to avoid additional expenses and requirements being added to the contract. Basic cost categories are shown below (in the table) for a traditional spreadsheet cost structure (from the MLCCM and the italic is the NASA 3-D cost structure). The structure used for reporting O&S costs for the current STS is also shown for comparison of the level of detail possible for an operational program in the NASA environment.

CAIG STRUCTURE

General cost structure for RDT&E.

Airframe RDT&E
- Engineering labor
  - Structures
  - Landing gear
  - Docking
  - Payload deployment and retrieval
  - Main propulsion
  - Orbital maneuvering system
  - Reaction control system
  - Avionics
  - Electrical/Mechanical power generation and distribution
  - Hydraulic power
  - Environmental control system
  - Flight personnel provision
- Tooling labor
- Training
- Manufacturing and quality control labor
- Other direct charges
  - Contractor support
- Manufacturing material

NASA 3-D STRUCTURE

2.1 Concept Development
- *2.1.1 Technology Programs*
  - *COSTS (across WBS's)*
    - *Hardware*
    - *Software*
    - *Facilities*
    - *Manpower*
    - *Other*
- *2.1.2 Phase A/B Contract Work*
  - *COSTS (across WBS's)*
    - *Hardware*
    - *Software*
    - *Facilities*
    - *Manpower*
    - *Other*

CAIG STRUCTURE

General cost structure for production.

- Airframe PRODUCTION
  - Production labor
    - Structures
    - Landing gear
    - Docking
    - Payload deployment and retrieval
    - Main propulsion
    - Orbital maneuvering system
    - Reaction control system
    - Avionics
    - Electrical/Mechanical power generation and distribution
    - Hydraulic power
    - Environmental control system
    - Flight personnel provision
  - Tooling labor
  - training
  - quality control labor
  - Other direct charges
    - Contractor support
  - Manufacturing material
  - data/documentation
  - infrastructure
  - indirect support
    - Facilities
    - personnel overhead
      - education
    - support (security and fire)

NASA 3-D STRUCTURE

- *2.2 Acquisition*
  - *2.2.1 Design and Development*
    - *2.2.1.1 Configuration Item*
      - *COSTS (across WBS's)*
        - *Hardware*
        - *Software*
        - *Facilities*
        - *Manpower*
        - *Other*
    - *2.2.1.2 Operations Capability Development*
      - *COSTS (across WBS's)*
        - *Hardware*
        - *Software*
        - *Facilities*
        - *Manpower*
        - *Other*
  - *2.2.2 Production*
    - *COSTS (across WBS's)*
      - *Hardware*
      - *Software*
      - *Facilities*
      - *Manpower*
      - *Other*
  - *2.2.3 Integration*
    - *2.2.3.1 Hardware Integration*
    - *2.2.3.2 HW/SW Integration*
  - *2.2.4 Test and Evaluation Phase*
    - *2.2.4.1 Ground Test*
      - *COSTS (across WBS's)*
        - *Hardware*
        - *Software*
        - *Facilities*
        - *Manpower*
        - *Other*
    - *2.2.4.2 Flight Test*
      - *COSTS (across WBS's)*
        - *Hardware*
        - *Software*
        - *Facilities*
        - *Manpower*
        - *Other*
  - *2.2.5 Program Management & Support*
  - *2.2.6 Program System Engineering*
    - *COSTS (across WBS's)*
      - *Hardware*
      - *Software*
      - *Facilities*
      - *Manpower*
      - *Other*

CAIG STRUCTURE

General structure for Operations and Support

- Direct labor
  - flight crew
  - Structures
  - Landing gear
  - Docking
  - Payload deployment and retrieval
  - Main propulsion
  - Orbital maneuvering system
  - Reaction control system
  - Avionics
  - Electrical/Mechanical power generation and distribution
  - Hydraulic power
  - Environmental control system
  - Flight personnel provision
- quality control labor
- training
- consumables (POL, etc.)
- Other direct charges
  - contractor support
- spares
- data/documentation
- infrastructure
- secondary spares transportation
- range safety
- indirect support
  - administration
  - Facilities
  - personnel benefits
    - education
  - support (security and fire)

NASA 3-D STRUCTURE

- *2.3 Program Operations and Support*
  - *2.3.1 Processing*
    - *2.3.1.1 Receiving*
      - *Safing*
      - *Inspection*
      - *Off-Loading*
    - *2.3.1.2 Scheduled Maintenance (Each Subsystem)*
      - *Access*
      - *Inspection*
      - *Maintenance*
      - *Servicing*
      - *Checkout*
      - *Closeout*
      - *Other*
    - *2.3.1.3 Unscheduled Maintenance (Each Subsystem)*
      - *Access*
      - *Inspection*
      - *Maintenance*
      - *Servicing*
      - *Checkout*
      - *Closeout*
      - *Other*
    - *2.3.1.4 Modifications*
    - *2.3.1.5 Verification & Checkout (Each Subsystem)*
    - *2.3.1.6 Transfer*
  - *2.3.2 Integration*
    - *2.3.2.1 Mating*
    - *2.3.2.2 Interface Verification*
    - *2.3.2.3 Transfer*
    - *2.3.2.4 Other*
  - *2.3.3 Launch Operations*
    - *2.3.3.1 Fueling and Fueling Activities*
    - *2.3.3.2 Crew and Crew Support Activities*
    - *2.3.3.3 System Verification*
    - *2.3.3.4 Launch System Verification*
    - *2.3.3.5 Launch Control Activities & Terminal Countdown*
    - *2.3.3.6 Nominal Support of Non-Nominal Operations*
  - *2.3.4 Mission Operations*
    - *2.3.4.1 Preflight*
      - *Mission Planning*
      - *Flight Planning*
      - *Flight Data Development*
      - *Flight Simulation*
      - *Crew Activity Planning*
      - *Flight Crew Operations*
      - *Payload Analysis & Integration*
      - *Training*
        - *Flight Crew*
        - *Ground Crew*

- *2.3.4.2 Flight*
  - *Ascent*
  - *Mission*
  - *Reentry*
- *2.3.4.3 Postflight*
  - *Data Analysis*
  - *Other*

2.3.5 Landing/Recovery
- *2.3.5.1 Flight Element Recovery*
  - *Recovery*
  - *Safe*
  - *Transportation*
- *2.3.5.2 Crew Recovery*
  - *Recovery*
  - *Transportation*

2.3.6 Non-Nominal Operations
- *2.3.6.1 Abort*
  - *Scrub/Hold*
  - *RTLS*
  - *Alternate Site*
  - *Abort to Orbit*
  - *Catastrophic*
- *2.3.6.2 Surge Activity*
- *2.3.6.3 Standdown Activity*

2.3.7 Logistics
- *2.3.7.1 Sparing Activity*
  - *Initial*
  - *Recurring*
- *2.3.7.2 Repair*
- *2.3.7.3 Training*
- *2.3.7.4 SRQ&M*
- *2.3.7.5 Communications*
- *2.3.7.6 Expendables/Consumables*
- *2.3.7.7 Transportation*
- *2.3.7.8 Storage*
- *2.3.7.9 Launch/Post Launch CleanUp*
- *2.3.7.10Other*
- *COSTS (across WBS's)*
  - *Hardware*
  - *Software*
  - *Facilities*
  - *Manpower*
  - *Other*

2.3.8 Base Operations
- *2.3.8.1 Base Ops*
- *2.3.8.2 Security*
- *2.3.8.3 Other*

CAIG STRUCTURE

General cost structure for Disposal (ideal)

- Direct labor
  - Structures
  - Landing gear
  - Docking
  - Payload deployment and retrieval
  - Main propulsion
  - Orbital maneuvering system
  - Reaction control system
  - Avionics
  - Electrical/Mechanical power generation and distribution
  - Hydraulic power
  - Environmental control system
  - Flight personnel provision
- safety labor
- training
- Other direct charges
- data/documentation
- transportation to disposal site(s)
- disposal of hazardous materials
- indirect support
  - administration
  - Facilities
  - personnel benefits
    - education
  - support (security and fire)

More likely cost element

- disposal cost

NASA 3-D STRUCTURE

2.4 Program Phaseout

COSTS (across WBS's)

- *Hardware*
- *Software*
- *Facilities*
- *Manpower*
- *Other*

The basic program phases for a generic program are research, development, test and evaluation, production, operations and support, and finally disposal. These costs are derived from the CAIG cost categories. The basis of selecting this level is that this is the typical level of cost tracking that is of concern to management (ie. Congress). This is the minimum required to effectively track costs in a program. In most programs there will be significantly greater indenture to this cost structure. In a conceptual environment going much beyond these levels will not usually add significantly to the understanding of the costs and their relationship to the total program. The costs below the levels shown represent increasingly less significant portions of the program cost and have historically not been tracked across many different programs nor has the methodology been consistent so that CER's could be created to predict costs at this level. If a significantly higher level of detail is required, the CER used usually predicts the cost at a higher level. This higher level cost may be apportioned by a fixed percentage to the lower levels based upon some understanding of the program at the lower level.

This discussion highlights the constant interplay between the ability to track every cost and implement it into a model of the entire program and the utility of predicting every cost at every level of the program. The desire of program management is to track or have access to every cost of the program at any time during the program's life, but the cost of tracking these costs by the contractor and the volume of data generated by tracking these cost would add significantly to the program costs without significantly adding to the utility of the tracking ability for management. The variability of the estimation of the costs for a conceptual program at high levels exceeds the cost at the lower level of the models used. The effort of the contractor to track costs at the level of the model to verify its results, in most instances, is cost prohibitive and adds very little to the ability to track the program at a management level. The overriding concerns must be is the information illuminating or obscuring to the development and management of the program and at what cost does this additional information not have utility worth the cost. This determination must be made on a program by program basis as to the utility of an additional level of detail for either the conceptual life cycle cost estimate or the cost tracking of a program.

STS OPERATIONS COST ESTIMATE (annual recurring)

Space Transportation System
- Shuttle Operations
  - Expendable Hardware
  - Reusable Hardware (refurb)
  - Operations
  - Program Office/Headquarters
  - Institution
  - PMS
  - Network Support
  - Systems Engineering
- STS Capability
  - Spacelab
  - ETB
  - Payload Operations
  - ROS (R&D)
- Shuttle Prod. & Oper. Cap.
  - Production
  - Pre-Planned Product Impr.

External Tank
- Mission Analysis
- Production
- Project Support
  - Logistics
  - MAF Communications
  - Slidell Computer Complex
  - Technical Evaluation and Analysis

SRM
- Sustaining Engineering
- Touch & Support Manufacturing & Refurb Labor
- SRM Propellent
- Expendable/Reusable Hardware
- Tooling Maintenance & Computer Support
- Freight
- Institutional Support

SRB
- Sustaining Engineering & Management
- Touch & Support Labor
- Expendable/Reusable Hardware
- Vendor Refurb of Reusable Hardware
- Travel, Computer & Other ODC
- KSC Support, Communications & Sys Analysis

Engine (sustaining engineering)
- Flight Support
- Anomaly Resolution
- Inventory Management & Warehousing
- Hardware Refurbishment
- New Hardware Spares
- Transportation

Orbiter & GFE (JSC)
- Sustaining Engineering & Launch Support
- Orbiter Support (by WBS)
- Flight Data Support
- Orbiter/ET Disconnects

Orbiter Logistics & GSE (KSC)
- Spares
- Overhaul & Repair
- Manpower to support Logistics, Procurement, Etc
- Tile Spares & Maintenance
- GSE Sustaining Engineering

Propellent (from Launch Ops(KSC))

Launch Operations (KSC)
- Shuttle Processing
  - Orbiter Operations
  - SRB Operations
  - ET Operations
  - Launch Operations
  - Payload Operations
- System Engineering/Support
  - Engineering Services
  - Systems Engineering
- Facility Operations and Maintenance
  - Facility O&M Support Operations
  - Facility Maintenance
  - Launch Shops (LES)
  - Facility Systems
  - Maintenance Services Contract
  - Inventory Spares & Repair
  - Systems Equipment
- LPS/Instrumentation and Calibration (I&C)
  - LPS Engineering and Software
  - LPS O&M
  - Instrumentation and Calibration
- Modifications
  - Shuttle Ops Funde

Modifications (facilities)
Technical Operations Support
Safety, Reliability, Maintainability and Quality Assurance
Logistics
Facility/SE Engineering
Operations Management
Non-IWCS Hardware, Software, and Maintenance
Launch Team Training System (LTTS) Program
Integrated Work Control System (IWCS) Development
Program Operations Support
Program Administration
Training
Human Resources
Communications
Voice Communications
Wideband Transmission and Navigation Aids Communications
Cable and Wire
Communication Support
OIS-D Implementation
Base Operations Contract (BOC)
Launch Support Services
Weather Support
Payload Operations
Payload Transportation & Interface Verification
Payload Processing GSE Sustaining Engineering
Mission Operations
Mission Operations Facilities
Mission Planing and Operations
Program & Doc. Support/Management

Crew Operations
Aircraft Maintenance
STSOC Flight Crew Ops Directorat Support
Crew Training and Medical Ops (JSC)
Program Office/Headquarters
Program Office
Headquarters
Institution
JSC
MSFC
KSC
Headquarters
SSC
PMS
JSC
MSFC
KSC
SSC
Total Network Support
Systems Engineering
MSFC Propulsion System Integration
JSC Engineering Directorate
White Sands Test Facility
JSC Center Ops
Ames
STS Capability Development
Spacelab
ETB
Payload Ops
ROS(R&D)
NLS
Advanced Programs
Shuttle Prod. & Oper. Capability
Production
Pre-Planned Product Improvement

2.7 Model Comparisons

The models presented are almost identical in their presentation of the basic costing structure. The differences are in the degree of detail presented. The 3-D model places most of its emphasis on the operations and support of the proposed vehicle while the planer model tries to place an equal emphasis on all phases of the life cycle of the vehicle. The planer model could have the same level of detail in the O&S phase if the information is available to create the CES's at the higher level of detail. The planer model can be implemented as a 3-D model if the user desires.

2.8 Recommendations

The most direct method to keep and maintain a viable LCC model for conceptual systems is to adopt the guidance issued by the CAIG for a cost estimating structure. The cost data from CAIG based systems will be more consistent in terms of its methodology, cost categories, and assumptions in tracking costs. A distinct advantage is the larger number of users for CAIG based LCC models (implemented in the MLCCM) used in conceptual analysis of aircraft systems thereby insuring consistency in cost categories. Allowances should be made for the unique aspects of the NASA mission and facilities, such-as range safety and pad maintenance. Most of the cost categories in the MLCCM structure are appropriate for a NASA model. The categories which are not appropriate, like military personnel in the administration can be eliminated with no loss in fidelity to the CAIG structure. A CAIG type cost structure will require some evaluation of the current cost tracking system used by NASA and determining the appropriate translations to make in terms of the appropriate CAIG category to which they belong. This is not an insurmountable task since the CAIG structure allows for unique program elements and these can be used for NASA unique cost categories.

The significance of data much below this level of detail for a conceptual vehicle is suspect. The inherent uncertainty of the predicted cost data will probably overshadow any cost categories below this level of detail. This does not mean that if reliable historic costs on which an accurate prediction can be made they should be excluded, just the opposite is true. Any costs for which there is a strong historic basis should be included, if for no other reason than completeness of the LCC model. These historic costs are best left to the people who have the most experience with them and their escalation throughout the use of the specially costed item.

More detailed engineering (accounting) based cost structure can be used once the systems have entered production and operation. If a significant historic database for costs in a category can be developed that cost category can be integrated into the conceptual model at a later time. Exquisite detail in the LCC model would be desirable but the greatest concern is that the data generated is credible and in most cases data generated at too low a level, when compared with the actual cost data has tremendous variability but the total system cost estimate remains close to the actual system cost. The low level cost will be a point of negotiation throughout the conceptual phase and into dem/val whereas the higher level will not require the constant defense of the costs presented that a more detailed model will elicit from all quarters as a reporting of the detailed costing would.

The recommendation is to use a CAIG-based (MLCCM) costing structure with modifications as required to meet the unique mission of NASA and the cost categories peculiar to a civilian organization which are not captured in a CAIG type model structure.

3.0 Life Cycle Cost (LCC) Models

Life cycle cost models are the formalized computation of the costs (usually in a common basis of money) of a system throughout its economic life. The economic life is from initial concept development to final disposal. The models are used to predict the economic impact of different maintenance concepts, integration of advanced technologies, etc. on the total program costs. They are also used to compare different programs to determine the most cost effective program over the economic life of the system.

3.1 Literature Review

A review of the existing life cycle cost models literature was conducted by searching computerized databases of periodic and published manuscripts. These included library, Defense Technical Information Center (DTIC) and NASA holdings.

The library holdings and the periodic literature were mostly generic methodologies on developing LCC models or predicting the production cost of a large number of consumer articles. There was very little utility in these references except as general background material. The DTIC and NASA documents were more illuminating.

The NASA and DTIC documents discussed high-tech systems in a low-production environment and their life cycle costs. The library references did not address the unique aspects of this type of system. The economic environment of a space vehicle is that the prototype or engineering built article will be a significant fraction of the number of vehicles constructed. The NASA and DTIC documents did include references to systems built in such an environment.

3.2 Relevant References

Of the many references in the bibliography there are a few which are especially noteworthy for their direct application to the development of cost estimating relationships for conceptual design space vehicles. These references include:

1) AFI 655-03 (former AFR 173-13)
2) Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Volume 5 - Cost
3) Conceptual Design and Analysis of Hypervelocity Aerospace Vehicles: Vol 3. Cost
4) Life Cycle Cost User's Manual (HVLCCM)
5) Modular Life Cycle Cost Model (MLCCM) for Advanced Aircraft Systems
6) NATO: Software Life Cycle Costing
7) Naval Fixed Wing Aircraft Operating and Support Cost Estimating Model
8) PREVAIL: Algorithms for Conceptual Design of Space Transportation Systems
9) Strategic Missile (Minuteman) Operating and Support Cost Factors (STRAMICE)
10) Unmanned Space Vehicle Cost Model, Sixth Edition (SD TR-88-97)

Each of these models is addressed in detail in Appendix A.

AFI 655-03 (former AFR 173-13), reference 1, is a compilation of cost data appropriate for anyone doing O&S life cycle cost analysis for current (and former) aircraft used in the US Air Force. The data includes military and civilian salaries, support costs by aircraft, and inflation indices. The use of these costs factors is mandated by the regulation to comply with the CAIG requirements. The most important aspect of AFI 655-03 is that it contains a generic O&S cost model. The CORE cost model has seven major cost categories with up to four levels of indenture (ie. 7.1.2.2.1 Officer), for a total of 93 entries. The main levels are: Unit Mission Personnel, Unit Level Consumption, Intermediate Maintenance (external to unit), Depot Maintenance, Contractor Support, Sustaining Support, and Indirect Support. The regulation is updated (at least) quarterly.

References 2 and 3 are the same document separated by three years, number 3 being the later of the two. This is an application of the standard modular life cycle cost model (MLCCM) to a hypervelocity vehicle. The vehicle can be manned or unmanned. The model was verified with shuttle data obtained from outside the contractor for the shuttle (congressional testimony, NASA documentation, etc.) and was found to predict the LCC of the shuttle relatively closely. This reference contains cost and manpower estimating relationships for R&D, production, and O&S life cycle cost for a hypervelocity vehicle. the model was designed to be run as a spreadsheet where the costs associated with each stage of the system is developed separately and then consolidated into a system summary of the life cycle costs over the life of the system. There are only minor revisions to the first document in the second.

Reference 4 documents the operation of the life cycle cost model developed in references 2 and 3 and is derived from reference 5. It explains how multiple stages (segments) of the vehicle can be costed separately using the appropriate CER or using actual cost data, if it is available, and then how the costs are to be accumulated in the appropriate subsystem. This accounting of costs complies with the guidelines of the CAIG. The program itself is implemented as a spreadsheet under LOTUS.

The modular life cycle cost model (MLCCM), reference 5, is the standard LCC model used by the US Air Force to comply with the CAIG directives. Most of the LCC models used in the Air Force are derived from this model. The model has more than 100 different data inputs and encompasses all phases of the life cycle (except disposal) of an avionic system life cycle. The model uses the type of material used in the different aircraft structures to determine the costs of materials, production, and repair based upon a comparison to standard aluminum practices. The shortcoming is the inability to predict disposal costs, but neither does any other appropriate LCC model.

Reference 6 is an attempt by NATO to develop a uniform method to estimate the life cycle cost of computer systems (software and hardware) used in C^3I systems. This reference surveys the different types of models used in developing the cost estimates, which include PRICE-S, COCOMO, etc. The driver used in estimating the other output parameters (facilities, personnel, etc.) is lines of code (LOC). The different models use different methods in developing this simple parameter, depending upon which computer language is used and the complexity of the application. The more sophisticated models also use the size of computer, the application to be hosted, if hardware is to be developed and if it is to be developed in tandem with the software, and what level of experience the team creating the software/hardware has in similar projects. The costs are in international accounting units (IAUs) to reduce the bias involved with selecting a particular monetary unit.

Reference 7 updates a Naval parametric Operating and Support estimating model using the CAIG guidelines for O&S cost analysis. The model updates 14 direct cost elements using 15 different aircraft types which represents the bulk of the Navy and Marine fixed-wing aircraft. Both linear and semi-log (log-linear) cost estimating relationships were developed for each of the direct cost elements. The presentation of the regression equations is the most complete of any of the models. The data points used, the residuals, outliers, and the fitting parameters are shown for each CER, this enables rapid verification of the CER or the development of different (exponential, etc.) relationships. The operational requirements and the maintenance philosophy used by the Navy prevents the direct application of many of the developed CER's for use in this study. The completeness of the data analysis in developing the CER's provides a basis of comparison between those developed for a space system and the CER's developed from the NAVY data. This allows a validity check of the space developed CER's by analogy with the NAVY CER's. The NAVY CER's can be used as a bound on CER's developed for conceptual space systems.

Reference 8 is geared toward a transportation system to place man and/or material in space. The costs are for three different configurations of vehicle (winged, aerodynamic and ballistic) with different launch scenarios. The model can be implemented on a PC using a spreadsheet.

Reference 9 is a summary of the cost model used by the former Strategic Air Command (SAC) to do a high level estimation of the costs associated with the strategic nuclear missile fleet. This high level fast response model relies heavily on readily available information contained in AFI 655-03 (former AFR 173-13) as input to the model. This model will run on a simple PC-based spreadsheet.

Reference 10 is the USAF Space Division's detailed analytic cost estimating relationships derived from eighteen unmanned space vehicles. The CER's are derived from regressions equations encompassing recurring and nonrecurring costs across system phases. The system phases include research and development, and production of space hardware from the component level (when available) through final assembly including normal program costs (like overhead and G&A). Some systems have over 3000 account names which were then incorporated into larger systems. This costing system is organized to be implemented as a PC based spreadsheet.

3.3 Cost Estimating Techniques

The cost estimating techniques (shown in figure 1, of section 2) are based upon the actual program cost information available to the analyst at that particular stage of the program. The use of parametric cost techniques occurs early in the program when the system is poorly defined and the actual cost can only be estimated, based upon previous systems. This estimation must be done carefully to avoid problems which will be discussed later. As the program progresses the degree of uncertainty in the design decreases and the reliance on cost estimating relationships (CER's) diminishes.

Analogy cost analysis requires a well defined program and system that is compared with similar projects to arrive at an estimate of the program cost. The analyst must use caution in applying the analogy and determining the correct allowances for differences between the two programs and systems.

Engineering cost estimates may be the most difficult and time consuming to determine. Almost complete cost data must be available for the smallest component to the largest system. This is a "bottom-up" analysis of costs. The cost at the lowest level of the system (component or individual) is accounted for and then rolled-up into courser divisions of cost. The process requires handling a large volume of data in minute detail. This is the beginning of an "accounting" type of cost estimating.

Actuals cost analysis relies on a rapidly maturing program where the requirements are fixed and the system is in initial production. Until the system is disposed of a system's cost will never be calculated entirely by the actual method. The disposal cost are unknown exactly until the disposal is performed. So even entering the disposal phase of a systems life cycle there will be some engineering estimates required to develop the costs of the system at this stage.

The accounting method relies upon a relative static financial entity with known historical costs. The use of cost estimating relationships (CER's) to predict costs requires historical cost data for similar financial entities and the best guess as to how the costs of the current financial entity differ from those which comprise the historic cost database from which the CER's were developed. The user of the CER must understand the limitation imposed upon the CER by the data from which the CER was estimated. Estimating costs with parameters outside of the original database must be approached with caution. Extrapolation of cost data is highly dependent upon the mathematical structure of the CER rather than the underlying historical data.

3.4 Life Cycle Costing

This study is concerned with predicting the costs of a conceptual space vehicle throughout its economic life (life cycle cost). Since there is no direct comparison possible with existing historical cost data for space vehicles, a cost estimating relationship (CER) based upon a cost element structure will be used. The actual cost structure is driven by both how the money is appropriated by Congress and more importantly how the costs have been tracked in the historic cost data base. Most of the cost data use in this study has been obtained from DoD sources, since they have the largest available cost database with relatively consistent cost categories across many different systems.

A typical project will go through a predictable life cycle, as shown in figure 1 of section 2 of this report. Initially the project will be in Research and Development (including testing and evaluation), Production, Operation and Support (including spares), and Disposal. A life cycle cost is the total dollar value of the resources (material, labor, etc.) that the project will consume from its inception to its ultimate disposal. An alternative structure for tracking life cycle costs is shown in Table I. These rolled-up cost categories typically have greater levels of indenture to explicitly show more specific costs of the system. An example of the level of indenture possible is the CORE model (shown in section 2) used in tracking of operating and support costs.

Table I Life Cycle Costs

Categories	Years of Life Cycle					
	1	2	3	...	n	TOTAL
Research and Development	$ aaa	$ bbb	$ ee	...	$ 0	$ MMM
Production	0	cc	fff	...	0	$ NNN
Operating and Support	0	d	gg	...	hhh	$ PPP
Disposal	0	0	0	...	i	$ QQQ
TOTAL	$ VVV	$ WWW	$ XXX	...	$ YYY	$ ZZZ

The life cycle cost models used by DoD are used primarily to support budget estimates, design to cost programs, and management reviews. Operating and support (O&S) costs by aircraft systems have little visibility in the day-to-day operations because of the structuring of the support segments by functional area and not aircraft. Estimates of O&S costs are of primary interest at major milestones of program development. The primary interest to the US Air Force in the O&S cost of a aircraft system is how does the proposed or system under development compare with the existing aircraft it is to replace.

Most of the DoD programs since 1960 have been reviewed and have been modified to ensure their reporting of cost is in compliance with the current CAIG directives on cost reporting and categories. This has resulted in a database of consistent costing data for advanced systems across 3 decades. To maintain consistency with the CAIG guidelines and make use of the data available we would propose to use a variant of the CORE model LCC structure (MLCCM), which adheres to the CAIG guidelines. This LCC model will meet the requirements of NASA and allow further growth as the database develops further.

3.5 LCC Models

There is a large number of government and commercial life cycle cost models. They all have one characteristic in common, they were all developed by a specific user for a particular immediate need. They also share the characteristics that they were developed for a specific kinds of projects in a particular financial environment with organizational peculiarities incorporated in the model to accurately reflect the organization and the project. Fortunately the number of models of interest to this project are quite limited due to the combination of unique characteristics. These unique characteristics are the government procurement of a limited production number of leading edge technology space capable vehicles. These characteristics make the LCC model requirements very specific.

The LCC model must be able to handle the government procurement of a space capable vehicle which has a long R&D phase funded yearly, a limited demonstration system production (1-5 vehicles), and a very restricted production of 5 to at most 10 times the number of demonstration vehicles. The vehicles themselves will be state of the art in many aspects with little chance to base costing on a similar type of system or subsystem because of the limited historic data for systems which could be similar (if they existed).

Commercially developed LCC models were eliminated from further consideration because of their lack of suitability to a space vehicle purchased by the government in small quantities. They also lacked continued support of the model over a long time period and verification of the CERs was virtually impossible since the original data from which the CER was derived was normally considered company proprietary. The models which have the most relevance comply with the CAIG requirements for cost reporting, so there is uniformity across models and the model will be supported for a number of years and the initial data is obtainable if the need arose to conduct verification studies of a particular cost estimating relationship.

3.5.1 "Flat" LCC models

The Air Force models all share a common ancestry with the AFLC (currently Material Command) Logistics Support Cost (LSC) model (currently Version 2.2a). This is a model developed in the early 1970's to be run on a mainframe computer. The early model was used in the selection process of the B-1 electronic countermeasures package and a variant of the model was used in the source selection process of the F-16[4]. To validate the model AFLC in 1990 contracted a validation study. MCR compared the results of DO41 (AFLC Recoverable Consumption Item Requirement System) to the model. DO41 is used by the Air Force for official requirements projections. MCR found that the current LSC model duplicates the results of the DO41 system predictions for the F-16 within their respective mathematical rounding routines. Using the LSC model represents significant speed increase in the estimates and a

[4] "Operating and Support Cost Estimating, A Primer", Major May, Air Command and Staff, 1982

savings in time to the users of the system. The DO41 system requires several years of actual data to begin to make predictions on the cost of support for different systems, whereas the LSC model makes predictions based upon historic data available at the beginning of a program.

3.5.2 3-D LCC Models

The evolution of more sophisticated PC-based spreadsheets with more capable PC's has lead to the diminution of the requirement of a mainframe computer based flat spreadsheet. The capabilities of the PC to manipulate and present visually complex 3-D data has lead to the evolution of the 3-D computer models of the life cycle costs of a program. With the present computer and program sophistication the visual format of a life cycle cost model is more a product of the users requirements and their method of presenting the information in the format that best suites their needs. The current 3-D models are a stack of "flat" spreadsheets with each page representing a phase of the life cycle formed into a cube.

The cube shape (figure 3.1)[5] allows the investigation of different relationships depending upon which view of the cube is used. If the investigator looks at the front of the cube the phases of the program can be investigated by looking at each layer of the cube. If a side view is taken the cost elements across phases and areas of activities can be investigated. If the cube is looked at from the top the areas of activities of the vehicle can be investigated across all cost elements and phases.

3.6 Constraints and Limitations

The goal of the LCC model prediction is to allow tradeoff studies of different vehicle configurations and maintenance concepts and determine on a relative basis what the impact will be on the total life cycle cost of the system. With the uncertainties inherent in developing an LCC model for a conceptual, state-of-the-art vehicle it is unreasonable to expect the predicted cost to be accurate to the decimal point. The conceptual LCC model tool will/should render order of magnitude estimates of the system costs using the best estimating techniques available at this time. Like all models of this type it will suffer from the assumptions made in developing the model. Chief among them will be the inflation indices used to predict then-year costs are accurate. This is clearly not the case in the short run (next five years) but over the 20^+ years of the system life the system predicted inflation factor should hold. The other assumption is that technology has a relative constant and predictable growth and the cost of the technology will behave as the current technology. In actuality technology breakthroughs are relatively common but unpredictable while technology stagnation is possible.

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[5] "Unmanned Space Vehicle Cost Model - Sixth Edition," Hillebrandt, et. al., Space Division/ACC, 1988

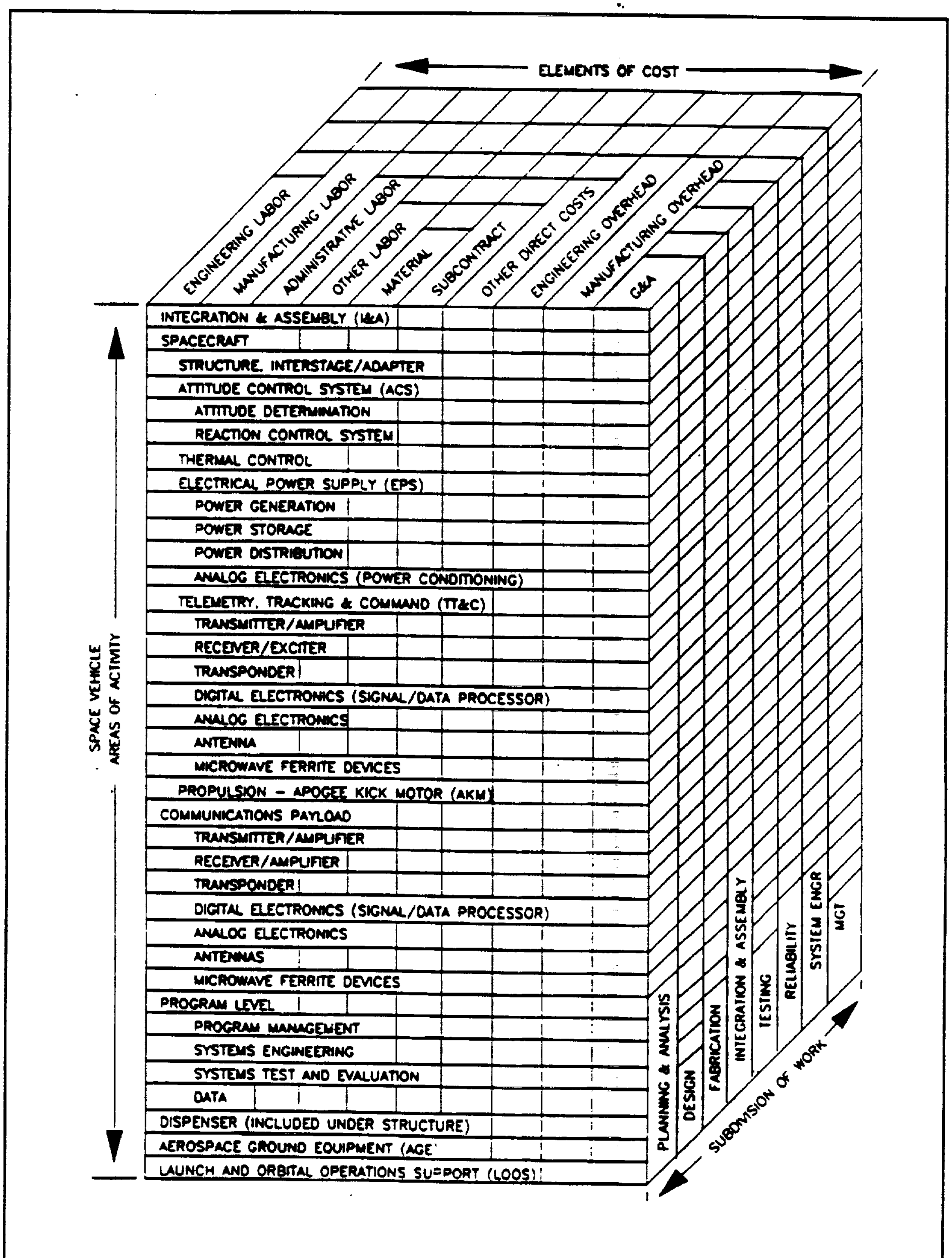

Figure 3.1 Industry 3-D Cost Data Matrix

With over 40 years of data on many different systems the experience has been that both technology breakthrough or stagnation are possible. A technology breakthrough could significantly reduce the costs associated with space vehicles resulting in the current model overestimating the costs of the system, or in the extreme it could render the current model obsolete if the breakthrough were significant. If technology stagnated and the current technology was used 20^+ years from now then the model would underestimate the LCC of the system. Both scenarios are unlikely to occur and most models take this middle ground where no significant breakthroughs or stagnations occur in the time-frame of the prediction of the LCC model for that particular system.

The final reason for recommending a CAIG-type CER structure and in particular one derived from the MLCCM (implementation of the CAIG directives) approach is that there is a revalidation of the MLCCM CER's underway and an enhanced variant of the current model currently underway. The detailed planning for the updated model will be completed in April of 1994 (subject to slippage). This model (revision) will be geared toward advanced (conceptual) design aerospace vehicles. The actual implementation (FY95-FY98) will be budgeted at $2.5 million. The future model will have the traceability and features currently not available in any model.

4.0 Methodology

4.1 General approach

The ultimate objective is the development of an automated life cycle costing model (LCCM) to be used during the conceptual design of a space transportation system. To meet this objective, the following steps are being pursued:

4.1.1 Design a cost element structure (CES) useful in the development, implementation, and execution of the LCCM. The structure must be compatible with existing LCC methodologies, be acceptable to NASA, and provide the necessary level of detail necessary to establish a reliable cost estimate. Section 2.0 documents the initial effort in the development of such a CES by identifying NASA's current CES and by providing a comparative analysis of the cost element structures used by current LCC models.

4.1.2 Summarize, compare, and contrast current LCC models which may adoptable in the space environment. These models were developed for use in costing aircraft, launch vehicle, and other space systems. The intent is evaluate the costing methodology and resulting relationships in order to adapt these relationships, where appropriate, to the current study. The objective is to use existing costing techniques to the extent possible. Section 3.0 summarizes those costing studies which may be relevant to this effort and attempts to identify those costing relations which may be utilized.

4.1.3 Identify those costing elements from the final CES which are not appropriately addressed in existing studies. For these cost elements, new cost data may have to be obtained and new cost relationships established. Currently, the general area of facilities (structures) has been identified as falling in this category. Section 5.0 discusses new costing relationships developed under this grant for use in facilties costing.

4.1.4 Integrate new and existing cost element relationships (CER's) into the CES in a logical and cohesive manner. This will require selective adaptation and, in some cases, modification of existing CER's. Input parameter data must consist of those performance and design specifications which can be determined during the early conceptual design of the vehicles. Some parameters may be estimated from knowledge of others. This will require the development of additional parametric equations similar to those developed in the Reliability and Maintainability model using primarily dry weight (a measure of the size of the vehicle) as the independent variable. Different LCCM's also have utilized different cost base years, therefore, using inflation indices, these cost estimates must be transformed to a common base year. In addition, the integrated model must allow for both discounting and inflation effects in order to present costs in both current year and then year dollars.

4.1.5 Develop a user-friendly computer model to implement the LCCM. This model should be compatible with the Reliability and Maintainability Model using both its input and output where appropriate to provide input to the LCCM. The computerized model will enable easy input of additional parameter values and provide a variety of output reports in support of the vehicle design studies. In particular, it should be suitable for performing trade and "what-if" studies.

4. 2 Cost Element Relationships

Cost estimating methods include engineering procedures, use of analogy, and parametric estimating. Engineering procedures requires low level and very detailed analyses of the design, material requirements and manufacturing processes to use in the production system. Time standards and other "engineered" standards would then be applied. Since this level of detail would not be known during the initial conceptual design, this is not a viable technique for use in this study. Estimates based upon analogy may be accomplished at any level. At the macro level, one may compare the costs of the shuttle to the cost of a proposed "shuttle-like" vehicle. Adjustments may then be made for difference in size, number of engines, performance, etc. For some subsystems and some functions this approach may provide the only means for obtaining a cost estimate since the shuttle is the only vehicle of its type and purpose (a sample size of one). Parametric estimating methods provide a statistical basis for establishing a relationship between costs and one or more "cost-drivers." This functional relationship is based upon historical data and uses regression analysis for establish the mathematical relationship. With the dependent variable being cost, independent variables such as weight, length, thrust, volume, quantities, etc. may be excellent "cost-drivers." Many of these CER's have been derived from aircraft data. To the extent the range of values of the independent variables encompass the space vehicle values, these relationships can be adopted for use in this study. Again, however, the independent variables must consist of those parameters which can be determined or estimated (perhaps themselves parametrically) in the early conceptual phase of the study. This will be the primary costing method utilized with analogy to the space shuttle as a secondary costing method.

4.3 Discounting and Inflation Adjustments

Since the various LCC models have differing historical base years, an inflation adjustment must be made to bring the costs to an initial 1993 base year. This adjustment will be based upon an average annual inflation rate, f, computed from producer or consumer price indices by solving the following for f:

$$PPI(t)\,(1+f)^n = PPI(1993)$$

where PPI(t) = producer's price index for year t and n = 93 - t.

Therefore,

$$f = \left[\frac{PPI(1993)}{PPI(t)}\right]^{\frac{1}{n}} - 1$$

and

$$COST_{93} = COST_{yr\ t}\ (1+f)^{93-t}$$

A further calculation is then made to adjust the cost to the base year identified by the user (assuming it is different from 1993) where f' is the average annual inflation factor for the period from 1993 to the base year (provided by the user). The final cost is then given by:

$$COST_{baseyr} = COST_{93}\ (1+f^{\prime})^{baseyr-93}$$

This cost is then applied to both nonrecurring and recurring costs over the life of the system in order to obtain constant dollars at the base year.

In order to obtain actual (i.e. then year) dollars for year t, the following additional calculation is performed:

$$COST_{yr\ t} = COST_{base\ yr}\ (1+f^{\prime})^{t-base\ yr}$$

When the costs are to be reflected in present value terms (at the base year), actual dollars in year t are adjusted as follows:

$$PV_{base\ yr} = \frac{COST_t}{(1+i)^{t-base\ yr}}$$

where i is the discount rate (provided by the user).

For constant dollars at year t, the present value adjustment will take the form:

$$PV_{base\ yr} = \frac{COST_t}{(1+i^{\prime})^{t-base\ yr}}$$

where

$$i^{\prime} = \frac{1+i}{1+f} - 1$$

This formula is derived from setting the present value of both the actual and constant dollars at the base year equal to each other.

4.4 Learning Curve Calculations

Production costs for major hardware purchases involving repetitive processes assumes decreasing unit costs as the production levels increase. Learning curves are generally based upon a constant percent savings for each doubling of the production quantity. To quantify this relationship, let

x = unit number produced,
Y_x = unit cost of the xth unit
K = cost of first unit
b = percent change in unit cost per doubling of production

$$Y_x = K\,x^n \quad \textit{where}\ n = \frac{\log b}{\log 2}$$

It is common for a production cost estimating equation to provide the production cost for a particular unit, say the 5th unit. It this case,

$$Y_5 = K\,5^{\frac{\log b}{\log 2}}$$

and, therefore

$$K = 5^{-\frac{\log b}{\log 2}}\,Y_5$$

since b is normally a specified input to the LCCM cost equation. Once K is determined the total cost for producing X units is given by

$$COST_X = \sum_{x=1}^{X} K\,x^n$$

5.0 Facilities

5.1 Facility Identification

Identification of facility requirements necessary to support systems that are in the conceptual design phase is, at best, difficult. Specific requirements of the system concerning the design, operational concepts and maintenance concepts have not been finalized. Additionally, areas such as support equipment development, spares requirements, or maintenance procedures in many cases have not been thought of yet or at best they are in their design infancy. In all likelihood, the design or procedures will change as the system develops and ultimately have a significant impact of the facility requirements needed to support the system. This section provides a methodology that can be used by space systems planners to estimate the gross facility requirements so that an initial life cycle cost can be derived for the proposed conceptual space system. This methodology will not consider facilities that are unique to an operational or maintenance feature of a specific system. These facilities (e.g., composite repair, heat absorbent material repair, etc.) will have to be identified and costed separately based on the information available concerning the facility. However, the methodology developed as a result of this research effort will provide a means to estimate the general facility requirements of a system. Parametric equations for facility square footage will be developed from data applicable to a wide range of aircraft currently in the United States Air Force inventory. Table 5.1, Study Aircraft (USAF), lists the US Air Force aircraft that were used in this study. The assumption here, is that future space systems will be aircraft like and use operational and maintenance procedures similar to those used in the United States Air Force and

TACTICAL	BOMBER	CARGO
A-7	B-52	C-130
A-10	FB-111	C-141
F-4		C-5
F-5		
F-15		
F-16		
F-106		

Table 5.1 Study Aircraft (USAF)

commercial aircraft industry. The approach used to identify the general facility requirements proceeded along two avenues that were merged to develop a list of facilities that are applicable in the proposed operational and maintenance concepts for the conceptual space systems. The first avenue, involved conducting an in-depth literature review of current information available on conceptual space vehicles. The purpose of this review was to determine the extent to which specific facilities are required to support the systems that have been identified. The second avenue, involved reviewing standard facility requirements identified to support current Air Force aircraft. The effort included a review of the procedures established by the Aeronautical System Center, Directorate of Systems Facility Engineering, Wright-Patterson AFB, Ohio, for identification of facilities required to support bed down of new aircraft weapon systems.

5.2 Literature Review

The literature review provided little insight into specific facility requirements for conceptual space systems. However, one study on the Advanced Manned Launch System provided the following information of the facilities required to support this system. The study summarized five major facility areas--landing site, horizontal processing facility, payload containment system processing facility, launch pad and launch/mission control center.

Landing Site. The landing site will be used for arrival of orbiter and booster elements at the launch site. The vehicles will arrive either from the manufacturer on a carrier aircraft such as the Boeing 747, or as part of recovery of the orbiter and boosters upon completion of a mission[1].

Horizontal Processing Facility. The Horizontal Processing Facility will consist of three areas--processing bays, mating bays, and storage bays. Vehicles will be processed in a horizontal position similar to commercial aircraft to decrease the facility height, decrease operational complexity, and permit ease of access to the vehicle elements. The overall impact of these decisions will be a reduction in the initial cost of the facility--using more standard construction techniques--reduce facility operating costs, as well as, the overall operating cost of the system[1].

Payload Containment System Processing Facility. The Payload Containment System Processing Facility consists of a single facility capable of performing minimal checkout and verification of the orbiter and its payload[1].

Launch Pad. The pad will have a minimal tower structure with few umbilical connections to the vehicle. The tower structure will provided access to the crew module and payload containment system[1].

Launch/Mission Control Center. The control center will allow for the integration of data from all aspects of the vehicle operations. Training resources, flight operations and launch control would reside within this one common complex.

[1] "Advanced Manned Launch System Study (AMLS), Interim Review, Rockwell International, June 1991

The support concepts for the various systems reviewed also provided some insight to the type of facilities needed to support these systems. The concepts represent a major change in the maintenance philosophy away from the concept currently used to support United States space vehicles toward one more similar to that of an aircraft where one-time certification with constant maintenance to ensure air worthiness of the vehicle is the normal certification and mainteneance proceedure for aircraft. The maintenance would be performed by airframe and propulsion technicians as is currently the practice in the commercial airline industry. The studies identified various airframe and propulsion skills that would be necessary to perform the various maintenance actions. These include:

Structural
Thermal Protection Systems
Helium Purge
Landing Gear and Auxiliary Systems
Main Propulsion
Prime Power
Electrical Conversion and Distribution
Surface Control Actuators
Avionics
Environmental Control
Personnel Provisions

Each of these skill in turn would require facility space to perform the maintenance required on the system.

5.3 Standard Facility Requirements

A review of current United States Air Force standard facility requirements, as well as, procedures used by the Aeronautical Systems Center to identify facilities to support bed down of aeronautical systems resulted the list of general operational and maintenance facilities shown in Table 5.2, General Operational and Maintenance Facilities.

FACILITY TYPE
Covered Maintenance Space
General Purpose Maintenance
Avionics Shop
Corrosion Control
Engine Maintenance
Maintenance Training
Base Operations/Control Tower
Squadron Operations
Flight Simulator Training Facility
Training Classroom
NDI Shop
PMEL Shop
Runway/Overruns
Taxiways
Aprons
Runway/Overruns
Runway/Taxiway Lighting

Table 5.2 General Operational and Maintenance Facilities

Additionally, the support facilities shown in Table 5.3, General Support Facilities, have also been identified as necessary for effective operations of United States Air Force aircraft systems.

FACILITY TYPE
Warehouses
Fire Station
Security
Telecommunications
Medical Clinic

Table 5.3, General Support Facilities

5.4 Facility Requirement Comparisons

A comparison of the facilities and technical skill identified by each avenue was then completed and the results are shown in Table 5.4, Facility/Skill Comparison.

AMLS STUDY	AIR FORCE FACILITY
Horizontal Processing Payload Containment System	Covered Maintenance Space
Landing Site	Runway, Taxiways, Aprons, Lighting, etc.
Launch/Mission Control, Training Facility	Base Ops, Control Tower, Simulator Trng/Classroom Fac, Squadron Ops
A&P TECHNICAL SKILLS	**AIR FORCE FACILITY**
Structural	Covered Maint Space General Purpose Shops
Thermal Protection System	Covered Maint Space
Main Propulsion	Engine Maint Shop
Prime Power, Electrical Conversion and Distribution	General Purpose Shops
Surface Control Actuators	General Purpose Shops
Avionics	Avionics Maint Shop
Environmental Control	General Purpose Shops

Table 5.4 Facility/Skill Comparison

A comparison reveals that facilities similar to those supporting United States Air Force aircraft will be required to support conceptual space vehicles using comparable maintenance concepts.

5.5 Estimation of Square Footage and O&S Costs

In this analysis, multiple regression techniques were used to determine parametric relationships for facility square footage and operations and support cost per aircraft as a function of various design, performance, and weight data. The first analysis performed was based on calculations of facility square footage--as outlined in Air Force Regulation 86-2, Standard Facility Requirements--necessary to support operation of current military fighter and cargo aircraft. The objective of this analysis was to develop a general means to estimate the facility square footage that would be necessary to support operation and maintenance of a conceptual space vehicle. The second analysis then compared historical operations and support cost in an effort to develop general cost estimating relationships that could be used in estimating the facility operations and support to be used in estimating the life cycle cost of a conceptual space vehicle. The following dependent facility variables were determined using regression analysis:

Y - Value (Dependent Variables)	Unit of Measure
Cover Maintenance Facilities	sq ft
General Purpose Maintenance Shops	sq ft
Avionics Maintenance Shop	sq ft
Corrosion Control	sq ft
Aircraft Engine Maintenance Shop	sq ft
Base Operations/Control Tower	sq ft
Squadron Operations	sq ft
Runway	linear ft
Fire Station	sq ft
Material Costs	$ per aircraft
Contract Costs	$ per aircraft
Other Costs	$ per aircraft
Personnel Costs	$ per aircraft

Table 5.5 identifies the independent variables and the range of the variable used in this analysis.

INDEPENDENT VARIABLE	DEFINITION	RANGE
NO_ENG	Total number of engines on each aircraft	1 -8
DRY_WGT	Weight of vehicle (without fuel) in pounds	9,500 - 320,000
LEN_WNG	Aircraft length plus wing span in feet	75 - 470
WET_AREA	Total external surface area of vehicle in sq ft	950 - 33,710
FUS_VOL	Total volume of the fuselage in cubic ft excluding any engine inlet duct volume	590 - 86,610
FUS_AREA	External area of fuselage in sq ft including canopy	550 - 16,650
AV_SSYS	Total number of avionics subsystems	10 - 37
HY_SSYS	Total number of hydraulic subsystems	16 - 76
TOT_VEH	Total number of vehicle per unit	15 - 72

Table 5-5, Independent Variables

Table 5-6, Facility Square Footage Requirement Parametric Estimating Relationships, contains the parametric estimating relationships for the general facilities identified in Section 5.3 as potential requirements that are similar to facilities that may be needed to support a conceptual space system.

Table 5-5, Facility Square Footage Requirement Parametric Estimating Relationships

FACILITY TYPE	EQUATION	RANGE	R^2
Covered Maintenance Space	$CON\ MNT = -324775.9 + 2.5907(DRY\ WGT) - 2383.25(LEN\ WNG) + 55728.93\sqrt{LEN\ WNG}$ $-24.015(FUS\ AREA) + 841.6011\sqrt{FUS\ AREA} - 1337.80(HY\ SSYS) + 971.0728(TOT\ VEH) - \frac{810225.2}{TOT\ VEH}$	35,000 - 200,000	0.9985
General Purpose Maintenance Shops	$GENPURP = 56212.07 - 0.5756(WET\ AREA) - 1.9567(FUS\ VOL)$ $+21.1749(FUS\ AREA) - 1046.75\sqrt{FUS\ AREA} - 1629.14\ln(TOT\ VEH)$	30,000 - 100,000	0.9985
Avionics Shop	$AV\ SHOPS = 565089.3 - 46.0272(LEN\ WNG) + 0.8305(WET\ AREA)$ $+2389.89(TOT\ VEH) - \frac{2{,}167{,}771}{TOT\ VEH} - 160572.7\ln(TOT\ VEH)$	30,000 - 100,000	0.9984
Corrosion Control	$CORR\ CTL = 54{,}702.65 + 205.9794(LEN\ WNG) + 0.1019(FUS\ VOL)$ $-15{,}529.68\ln(LEN\ WNG)$	10,000 - 100,000	0.9997
Engine Maintenance Shop	$ENG\ MNT = 187{,}272 + (FUS\ VOL) - 22.6943(FUS\ AREA) + 773.0399\sqrt{FUS\ AREA}$ $-8{,}104.0(NO\ ENG) - \frac{40{,}638.6}{NO\ ENG} - 3{,}024.79\ln(AV\ SSYS) - 27{,}836\ln(TOT\ VEH)$	10,000 - 80,00	0.9977
Squadron Operations	$SQ\ OPS = 263{,}506.8 - 589.97(NO\ ENG) - 16{,}788.68(TOT\ VEH)$ $+409{,}852.7\sqrt{TOT\ VEH} - 584{,}249.3\ln(TOT\ VEH)$	7,000 - 60,000	0.9995

Table 5-6, Facility Square Footage Requirement Parametric Estimating Relationships (Cont)

FACILITY TYPE	EQUATION	RANGE	R^2
Runway	$RUNWAY = 5{,}444.83 + 0.08443(DRY\ WGT) - 0.2322(FUS\ VOL) - 137.1295\sqrt{FUS\ VOL} + 2.1638(FUS\ AREA) - 1{,}094.07(NO\ ENG) + 1{,}783.08\sqrt{NO\ ENG} + 619.8861\ln(AV\ SSYS) + \frac{20{,}518.04}{AV\ SSYS}$	5,000 - 20,000	0.9999
Fire Station	$FIRE\ STAT = 12{,}224.79 + 14.3598(LEN\ WNG) + 370.9842(NO\ ENG) + \frac{739.2172}{NO\ ENG} - 1{,}385.76\ln(LEN\ WNG)$	8,000 - 13,000	0.9931
Base Ops/Ctl Tower	BASE_OPS = 9,800 (sq ft)	N/A	N/A
Security Police Ops/Pass and ID	SEC_POL = 6,900 (sq ft)	N/A	N/A
Telecommunications Facility	TELECOM = 5,000 (sq ft)	N/A	N/A
NDI Shop	NDI = 4,000 (sq ft)	N/A	N/A
PMEL Lab	PMEL = 5,000 (sq ft)	N/A	N/A
Maintenance Training	MNT_TRNG = 20,000 TO 30,000 (sq ft)	N/A	N/A
Taxiways	TAXIWAY = 10,000 TO 20,000 (lin ft)	N/A	N/A
Warehouse	$WAREHOUSE = -498{,}939.5 - \frac{19{,}027.40}{DRY\ WGT} + 275.0749\sqrt{DRY\ WGT} - 992.8392\sqrt{WET\ AREA} + 5.2777(FUS\ VOL) + \frac{4.013e04}{FUS\ VOL} - 34.1129(FUS\ AREA) + 113{,}650.8\ln(LEN\ WNG)$	11,000 - 70,000	0.9827

5.6 Operating and Support Costs

Facility operation and support cost ($ per aircraft) parametric estimating relationships were developed to estimate the yearly cost to operate, repair and maintain the facilities necessary to support the anticipated operational and support concepts of a conceptual space vehicles or systems. The objective for providing these equations is to provide space system planners with a means to identify an initial "ball park" estimate of the facility operation and support cost requirements that will form the basis for performing initial facility life cycle costing on the proposed space system.

The operations and support cost data was obtained from the Visibility and Management of Operating and Support Cost (VAMOSC) System. The costs included those allocated to the personnel assigned to the maintenance and operation of real property facilities and related management and engineering support work and services. The costs also include those associated with materials, contract and other expenses associated with maintenance of real property facility assets. The cost data used to develop the parametric cost estimating relationships was the total yearly aggregated cost for a specific weapon system and mission design series ($ per year and aircraft type). No relationship exists between operation and support cost parametric estimating equations and the size and type of facility. The cost of a specific type of facility type ($ per square foot) could not be obtained for use in the development of the operation and support cost parametric estimating equations.

The operating and support cost parametric estimating equations (Table 5.7) are derived from fiscal year 1989 operation and support cost for the twelve specific aircraft identified in Table 5.1, Study Aircraft (USAF). Four specific cost areas were identified in the Visibility and Management Operating and Support Cost database and they included material, contract, other and personnel costs needed to maintain and repair the facilities necessary to support the mission of the aircraft selected.

Material Costs: This data includes all costs expensed for materials associated with the repair and maintenance of real property facilities identified by specific command and geographical location codes (OAC/OBAN codes). The costs must also carry a PEC code of XXX94 for real property maintenance cost expenses with Element of Expense Investment Code of 60XXX through 63XXX.

Contract Costs: This data includes all costs associated with real property facility maintenance that was completed by contract and are identified by specific command and geographical location codes (OAC/OBAN codes). These costs must also carry a PEC code of XXX94 for real property maintenance cost expenses with Element of Expense Investment Code of 51XXX through 59XXX.

Other Costs: This data includes all remaining Element of Expense Investment Codes associated with real property facility maintenance within PEC code XXX94.

Personnel Costs: This data includes all costs allocated to personnel assigned to the maintenance, repair, and operation of real property facilities and related management and engineering support work and services.

Table 5.7, Facility Operation and Support Cost Requirement Parametric Estimating Relationships

COST CATEGORY	EQUATION	R^2
Material	$\mathit{MATERIAL} = 94{,}327.79 + 0.6206(\mathit{DRY\ WGT}) - 301.5694(\mathit{LEN\ WNG}) - \frac{4{,}787{,}331}{\mathit{LEN\ WNG}} - 6.5950(\mathit{FUS\ AREA})$	0.5723
Contract	$\mathit{CONTRACT} = 94{,}577.05 - \frac{4{,}938{,}749}{\mathit{LEN\ WNG}} + \frac{935{,}698.6}{\mathit{WET\ AREA}} + \frac{5{,}741{,}874}{\mathit{FUS\ VOL}} - 379.7252(\mathit{HY\ SSYS})$	0.5179
Other	$\mathit{OTHER} = 16{,}578.32 - 0.8060(\mathit{WET\ AREA}) + 18{,}456.13\ln(\mathit{NO\ ENG})$	0.9940
Personnel	$\mathit{PERSONNEL} = 174{,}076.9 - \frac{1010e04}{\mathit{LEN\ WNG}}$	0.8392

5.7 Construction Costs

Facility construction costs were obtained from the Historical Air Force Construction Handbook, Air Force Civil Engineering and Support Agency, December 1992[2]. The document provides Air Force facility planners with valid historical cost data to be used in the preparation of cost estimates and related cost analysis for all Air Force facility construction projects. The data for this document was obtained form the Air Force Program, Design and Construction system, on line computer data base, that tracks the current status, project estimates, scope, low bids, and construction schedules for all facility construction projects approved for design and construction in the Air Force Military Construction Program. The specific unit cost data is the Air Force historical average unit price for new facility construction.

The data contained in Table 5.8, Facility Construction Cost Data, show the specific construction cost for the facilities identified in Section 5.3 as potential facilities required to support operation of conceptual space vehicles and included as a part of this study (See Table 5.2, General Operational and Maintenance Facilities, and Table 5.3, General Support Facilities). The facility construction costs have been normalized to October 1993 (Fiscal Year 94).

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[2] "Historical Air Force Construction Cost Handbook," USAF Engineering Support Agency, 1992

FACILITY TYPE	UNIT	$/UM
General Operational and Maintenance		
Covered Maintenance Space	SF	132.00
General Purpose Maintenance Shops	SF	89.00
Avionics Shops	SF	117.00
Corrosion Control	SF	128.00
Engine Maintenance Shop	SF	88.00
Maintenance Training	SF	100.00
Base Operations	SF	100.24
Control Tower	SF	297.00
Squadron Operations	SF	100.00
Flight Simulator Training Facility	SF	153.00
Flight Training Classroom	SF	100.00
NDI Shop	SF	142.00
PMEL Shop	SF	114.00
Runway/Overruns	SF	16.00
Taxiways	SF	16.00
Aprons	SF	16.00
Approach Lighting (One End)	EA	403K
End of Runway Lighting (One End)	EA	282K
Runway Edge Lights (Cost Includes Both	LF	84.00
Taxiway Edge Lights (Cost Includes Both	LF	147.00
General Support Facilities		
Warehouses	SF	46.00
Fire Station	SF	95.00
Security	SF	104.00
Telecommunications	SF	148.00
Medical Clinic	SF	138.00

Table 5.8, Facility Construction Cost Data

6.0 Conclusions

Based upon the April 1993 proposal titled "Life Cycle Cost Modeling of Conceptual Space Vehicles," the additional effort on Grant No. NAG-1-1327 is on schedule. The first three tasks have been completed. Task four has been completed as pertains to facility costing; however, the possibility exists that additional regression analysis may be performed if it appears to enhance the LCC model being developed. Task five has been initiated with the integration of the proposed Cost Element Structure (CES) with existing and new cost estimating relationships (CERs). Task five also included defining the methodology for computing in both current year and then year dollars. Task 6 has also begun with the development of PC based software to implement the LCCM. Task 7, upgrades to the Reliability & Maintainability model have identified earlier. It is expected that additional changes and upgrades will be achieved during the remainder of this research period.

With a visit to the Langley Research Center planned shortly after the first of the year, it is anticipated that the scope and direction of the remaining effort will be established. As a result of this meeting, the remaining activity on tasks five and six should result in a computerized LCC model which will assist the user in performing cost analysis on conceptual space vehicles.

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Appendix A

Life Cycle Cost Model Summaries

MODEL: Avionics Laboratory Predictive Operations and Support (ALPOS) Cost Model

REFERENCE: "A Comparison of Various Life Cycle Cost Models," Welch, 1985

COMPUTER IMPLEMENTATION: CDC-6600 mainframe, Fortran IV

APPLICATION: parametric O&M cost estimate of avionics equipment

SOURCE OF DATA: regression of avionic equipment data

INCLUDES: 15 estimating equations derived from logistics, support, and cost parameters derived from 10 dependent and 20 independent variables

EXCLUDES:

STAGES: operation and maintenance

INPUTS: MMH/OH, MTBF, unit price, unit volume, weight, component type, BIT/FIT factor, number of SRUs per LRU, aircraft type, operating hours per month

WBS: not explicitly stated

SUBSYSTEMS: user input

MODEL: CORE (and ZCORE)

REFERENCE: "Review of Selected USAF Life Cycle Costing Models," Twomey, 1991

COMPUTER IMPLEMENTATION: PC based in BASIC

APPLICATION: constant year LCC estimation of O&S costs

SOURCE OF DATA: AFI 655-03 (former AFR 173-13)

INCLUDES: eight primary cost categories (Unit Mission Personnel, Unit-Level Consumption, Depot-level Maintenance, Sustaining Investment, Installation Support Personnel, Indirect Support Personnel, Depot Nonmaintenance, and Acquisition and Training), class IV modifications, contractor logistics support

EXCLUDES: factors below the system (aircraft) or subsystem (radar, APU, etc.) level are not covered, vary resource inputs (manpower, etc.), aircraft availability

STAGES: O&S

INPUTS: system operating parameters and characteristics

WBS: WUC structure

SUBSYSTEMS: WUC structure

MODEL: Frieman Analysis of Systems Technique (FAST-E)

REFERENCE: "A Comparison of Various Life Cycle Cost Models," Welch, 1985

COMPUTER IMPLEMENTATION: PRIME mainframe

APPLICATION: computerized parametric cost estimating model used primarily by the energy industry to estimate equipment and system costs

SOURCE OF DATA: regression of equipment and system parameters as they relate to cost

INCLUDES: technology maturity (electronic, electrical, heat, motion, mechanical control, containment and supportive components), design masses (energy conversion, design overhead, application, dimensional, and conditional), weight, size, economics of production, engineering,

EXCLUDES:

STAGES: engineering, production, and installation

INPUTS: characteristics (see INCLUDES) of the system or equipment under study

WBS: not applicable

SUBSYSTEMS:

MODEL: Hypervelocity Life Cycle Cost Model (HVLCCM)

REFERENCE: "Users Guide Program HVLCCM," 1989, "Life Cycle Cost User's Manual," Albin, Boeing Aircraft Company, 1989

COMPUTER IMPLEMENTATION: mainframe (Fortran 77) and PC (spreadsheet)

APPLICATION: conceptual military hypervelocity aircraft LCC model

SOURCE OF DATA: modification of MLLCM (cargo plane) based on shuttle data

INCLUDES: PHASES 3 and 14 systems and subsystems, direct and indirect costs, RDT&E (5 CERs), System and Support Investment (Production) (12 CERs), O&S (85 CERs)

EXCLUDES: final disposal

STAGES: 3 and summary

INPUTS: vehicle operational characteristics (fuselage volume, weight, etc.), materials used by subsystem structure, tooling, payload characteristics (volume, weight, etc), system parameters, life cycle, G&A percentage, profit, number of prototypes, production numbers

WBS: RDT&E, production, O&S

SUBSYSTEMS: structure, landing gear, docking, payload Deployment & Retrieval, main propulsion, orbiting maneuvering, RCS, avionics, electrical/mechanical power generation and distribution, hydraulics, ECLS, flight provision, engine installation

MODEL: Logistics Support Cost (LSC) Model

REFERENCE: "User Documentation for the AFLC Logistics Support Cost Model version 2.2a," AFLC, 1991, "Review of Selected USAF Life Cycle Costing Models," Twomey, 1991

COMPUTER IMPLEMENTATION: PC based in Basic

APPLICATION: Operating and Support Cost model at the LRU/SRU level

SOURCE OF DATA: AFLCP 173-3 and AFR 173-13

INCLUDES: initial and replenishment spares, depot maintenance, second destination charges, condemnation spares and spares used to fill the logistics pipeline

EXCLUDES: connection of spare cost to aircraft availability and logistic system, preventive maintenance

STAGES: not typically used prior to Milestone III of a program, O&S costs

INPUTS: ASCII file input of SRU and LRU costs and characteristics, and avionic system characteristics (size, weight, flight hours, etc.).

WBS: three to four (some five) digit WUC structure

SUBSYSTEMS: most subsystems are included in this "accounting-type" model.

MODEL: Modular Life Cycle Cost Model (MLCCM) for Advanced Aircraft

REFERENCE: "MLCCM for Advanced Aircraft Systems-Phase III, Volume VI, rev. 2," 1985, "MLCCM for Advanced Aircraft Systems-Phase III, Volume IV, rev. 3," 1986, "Review of Selected USAF Life Cycle Costing Models," Twomey, 1991

COMPUTER IMPLEMENTATION: Mainframe (CYBER 750 and NOS2 O/S in FORTRAN), PC spreadsheet (LOTUS)

APPLICATION: military aircraft life cycle costing

SOURCE OF DATA: regression of USAF aircraft systems and subsystems

INCLUDES: 4 PHASES, 12 systems/subsystems, MIL and CIV personnel, materials, contract costs (G&A, overhead, profit)

EXCLUDES: final disposal

INPUTS: system operational parameters, and characteristics (ie. weight, length, fuel consumption, construction material, etc.) and costs if known

WBS: Phases: rdt&e, production, initial support, and O&S

SUBSYSTEMS: structures, crew system, landing gear, flight control, engines, ECS, electrical system, hyd/pneumatic system, fuel system, avionics, cargo handling(or armament)

MODEL: Naval Fixed-Wing Aircraft Operating and Support Cost-Estimating Model

REFERENCE: "Naval Fixed-Wing Aircraft Operating and Support Cost-Estimating Model," DRC, 1986, "Naval Fixed-Wing Aircraft Operating and Support Cost-Estimating Model," DRC, 1990

COMPUTER IMPLEMENTATION: PC based spreadsheet (LOTUS)

APPLICATION: Naval Fixed-Wing Aircraft Operating and Support Parametric Cost Estimates

SOURCE OF DATA: regression (linear and log-linear) of current Navy aircraft cost data

INCLUDES: Direct and Indirect costs of 15 current Navy aircraft types (A-4F, A-4M, A-6E, A-7E, AV-8B, KA-6D, EA-6B, F-4S/J, F-14A, F/A-18A, E-2C, S-3A, P-3C, T-39D, and T-44A), in CAIG structure (total of 27 cost elements). FY1990 base year dollars.

EXCLUDES: emergency repair and support costs - regression equation did not provide significant results (low adjusted coefficient of determination ("goodness-of-fit")), modification procurement - unable to segregate costs for emergency versus non-emergency modification of aircraft

STAGES: O&S

INPUTS: personnel by job function (air or ground crew, maintenance, etc.), pay rates, flying hours, empty loaded, empty, airframe, and engine weight of aircraft, maximum aircraft speed at sea level, number of engines, maximum thrust per engine, cost of procurement of safety related items, POL costs, cost of first 100 aircraft, aircraft rework cost/yr, and unscheduled maintenance manhours per aircraft.

WBS: CAIG structure

SUBSYSTEMS: none

MODEL: PREVAIL

REFERENCE: PREVAIL Algorithms for Conceptual Design of Space Transportation Systems

COMPUTER IMPLEMENTATION: FORTRAN 77 on a MAINFRAME (CDC Cyber, VAX, IBM 3090) and IBM PC.

APPLICATION: Sizing and cost of launch and orbital transfer vehicles

SOURCE OF DATA: Centaur, IUS, Titan III, STS (Shuttle)

INCLUDES: Subsystem (15) CER's for three primary cost categories: Design Engineering, Test and Evaluation, and Production for LO_2-LH_2 motors, solid rocket motor, winged stages and whether the stages are manned or reusable.

EXCLUDES: Cost for ground equipment, facilities, military pay, sharing of common subsystems, horizontal launch.

STAGES: reusable or expendable liquid oxygen, liquid hydrogen, solid rocket motor, liquid fuels, winged or manned stages.

INPUTS: vehicle/subsystem parameters, launch parameters, payload parameters, orbital parameters

WBS: 15 primary systems/subsystems in three cost categories

SUBSYSTEMS: structures, thermal, reentry protection, landing system, electrical-power, electrical-wiring, guidance&control, data handling, instrumentation, communications, propulsion systems, engine(s), RCS, interstage adapter, payload faring.

MODEL: Programmed Review of Information for Costing and Evaluation (PRICE)

REFERENCE: "A Comparison of Various Life Cycle Cost Models," Welch, 1985

COMPUTER IMPLEMENTATION: mainframe

APPLICATION: life cycle costing of electro-mechanical hardware assemblies and systems

SOURCE OF DATA: RCA - purchase of network time

INCLUDES: design, drafting, project management, documentation, sustaining engineering, special tooling and test equipment, government furnished or modified equipment, material, labor, testing, and overhead

EXCLUDES: non-hardware costs of field test, site construction, and software

STAGES: development, production, purchase

INPUTS: quantity of equipment, schedule, hardware geometry (size, weight,etc.), complexity, operational environment, fabrication process, fixed and variable costs of material, facilities, and labor, and technology improvement

WBS: none implicit in the model

SUBSYSTEMS: none implicit in the model

MODEL: Reliability, Maintainability and Cost Model (RMCM)

REFERENCE: "Adapting Logistics Models to a Microcomputer for Interface With Computer-aided Design Systems," Davidson and Fraser, 1984, "A Comparison of Various Life Cycle Cost Models," Welch, 1985

COMPUTER IMPLEMENTATION: CDC-6600 Cyber 74 mainframe, using Fortran IV

APPLICATION: weapons system and support equipment's life cycle costs used to conduct requirements, costs, and trade-off analyses

SOURCE OF DATA:

INCLUDES: recurring, nonrecurring, and disposal costs

EXCLUDES:

STAGES: conceptual, development, production, and operation and support

INPUTS: reliability and maintainability of subsystems, unit costs, number of units procured, depot repair cycle time, etc.

WBS: three to four digit level of the WUC structure

SUBSYSTEMS: at the LRU level (see WBS)

MODEL: TI-59 Handheld Calculator Aircraft Top Level Life Cycle Cost Model (TI-59 ATL^2C^2)

REFERENCE: "A Comparison of Various Life Cycle Cost Models," Welch, 1985

COMPUTER IMPLEMENTATION: TI-59 Handheld Calculator

APPLICATION: flyaway cost of quantity 750 aircraft

SOURCE OF DATA: LSC model

INCLUDES: 42 inputs (30 default)

EXCLUDES:

STAGES: RDT&E, Production, initial and recurring O&S

INPUTS: required: empty weight, material of airframe % (3), rated thrust of engine (military-uninstalled, 30 minutes), number of engines, avionics weight per aircraft

WBS: none specified by model

SUBSYSTEMS: none specified by model

MODEL: Unmanned Space Cost Model 6 (USCM6)

REFERENCE: "Unmanned Space Vehicle Cost Model," US Air Force Space Division, 1988

COMPUTER IMPLEMENTATION: PC - LOTUS spreadsheet

APPLICATION: CERs for estimating hardware costs of earth-orbiting space vehicles

SOURCE OF DATA: regression of historic earth-orbiting space vehicles (18 programs)

INCLUDES: recurring and nonrecurring costs for: Payload (mission equipment), Spacecraft, Aerospace Ground Equipment, Launch & Orbital Operation Support, Integration and Assembly, Program Level, Dispenser (including structure), Structures & Interstages, ACS, Thermal Control, EPS, Telemetry, Tracking and Command (TT&C), Apogee Kick Motor (AKM) (propulsion), and Communications

EXCLUDES: Ground C^3, Launch Vehicle, Sensors, Cameras, and Other Payloads

STAGES: Purchase of the hardware

INPUTS: Structure, Apogee Kick Motor (AKM), and Altitude Control System weight, Space vehicle weight, electrical power weight, power required, AKM impulse and stabilization, mission equipment weight, number of solar cells, communications subsystem weight, number of altitude sensors and weight, RF power output, receiver/exciter design life, weight of subsystems, G&A costs, profit, and number of vehicles

WBS: I. Space Vehicle, A) Integration and Assembly, B) Spacecraft, 1. structure, interstage/adapter, dispenser, 2. altitude control system, 3. thermal control, 4. electrical power supply, 5. telemetry, tracking & command, 6. apogee kick motor, C) Communications Payload, D) Program Level - program management, systems engineering, systems test and evaluation, data, II. Aerospace Ground Equipment, III. Launch & Orbital Operations Support

SUBSYSTEMS: see INCLUDES